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EXPERIMENTAL REFINEMENT OF CALCULATED FORMULAS FOR THE DISTRIBUTION OF POTENTIAL IN ELECTROCHEMICAL PROTECTION OF SHIPS FROM CORROSION

Yu.L. Kuz'min

Tsentr. Nauchno-Issled. Inst.Tekhnol Sudostr., Leningrad USSR 8, 1 (1972) 40-44

(from Russian)

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Translated by Dr. B.F. Toms

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The calculated relationships of distribution of potential over the underwater surface of ship's hulls have been established for the principal types of electrochemical protection taking account of the geometry and dimensions of the hull and the state of its paintwork.

The familiar techniques of calculating the electrochemical protection of ships from sea water corrosion[1,2] are based on the assumption that current distribution over the protected surface is uniform. In fact, the distribution of current and potential over the surface of the hull is far from uniform, and this must be taken into account in calculations of electrochemical protection[3,4].

To determine the outer limit of the zones of protective action, i.e. the zones within which cathode polarization is sufficient to ensure protection from corrosion, the potential distribution at a considerable distance from the anodes and protectors must be found. The ratio of the dimensions of the zones of protective action and the dimensions of the actual anodes (protectors) is usually so great that as an approximation we can use formulas for the distribution of the potential of point sources of current disposed above and on a linearly polarized infinite surface of protected metal[5].

The potential distribution for a point source disposed above a linearly polarized plane is defined by the expression[4]

$$\Delta\varphi(r) = \frac{Ib\gamma}{2\pi} \int_0^\infty \frac{pe^{-ph}}{b\gamma p + 1} J_0(pr)dp, \qquad (1)$$

where $\Delta\varphi(r)$ is the shift of potential produced by cathode polarization; r, z (sic) are the cylindrical coordinates of the point at which potential is determined; I is the output of the point source of current; b is the specific cathodic polarizability of the protected metal; γ is the electrical conductivity of the medium; and $J_0(pr)$ is a zero-order Bessel function of the first kind. For a painted protected surface for which formula (1) is also applicable[8] we must substitute for b the value of the specific surface resistance of the paint coating ρ_p which plays the same role as b in the mechanism of electrochemical protection.

We took formula (1) as a starting point for establishing the calculated dependences of potential distribution for anodes with insulation shields, since the potential distribution with the introduction of an insulation shield in the remote zone is approximately the same as for a point source shifted away from the plane.

Experimental studies of potential distribution were carried out with a hull plating model and on a number of ships for anodes with shields of various dimensions. The measurements thus obtained were compared with the results of calculations using formula (1) for different distances of the point source from the plane h. It may be observed (Fig. 1) that at distances from the centre of the anode exceeding the linear dimension of the shield the points of measurements practically coincide with the results of calculations for all considered values of h. At shorter distances the best agreement between the results of calculation and measurements is observed when $h = 0.2\ l_s$. Analogous results are obtained in measurements on the model with shields of other dimensions. The ratio obtained also agrees well with the results of measurements of the potential distribution near anodes with shields on vessels of high tonnage where the surface of the hull has a fairly long plane area, and consequently limitation of the dimensions and the curvature of the lines of the hull have practically no effect. Thus, in approximative calculations of potential distribution using formula (1) the dimensions of shields round the anodes may be taken into account by assuming that $h = 0.2\ l_s$.

In calculations of potential distribution for protectors and protector groups (mounted on the hull without insulation shields as a rule) the calculation model can be assumed to be in the form of a point source situated directly on the plane surface of the protected metal. In this case, as was demonstrated by Yu.Ya. Iossel, the following expression for the potential is obtained:

$$\Delta\varphi(r) = \frac{I}{2\pi\gamma r}\left\{1 - \frac{\pi r}{2b\gamma}\left[E_o\left(\frac{r}{b\gamma}\right) - N_o\left(\frac{r}{b\gamma}\right)\right]\right\} \qquad (2)$$

where $E_o\left(\frac{r}{b\gamma}\right)$ and $N_o\left(\frac{r}{b\gamma}\right)$ are zero-order Weber and Neuman functions. Formula (2) was taken by us as the starting point for establisning the calculated dependences of potential distribution for single protectors and small protector groups mounted on the hull with no insulation shield.

To allow for the influence of the dimensions and lines of the hull experimental coefficients were introduced in formulas (1) and (2). The numerical values of these coefficients were determined by comparing the results of calculation with the results of measurements of potential on different ships. For each ship the specific surface resistance of the paint coat of the underwater surface averaged over the hull was measured by a specially developed technique. In the calculations we used the values of the specific surface resistance of the coating and the electrical conductivity of the medium which were found when the measurements were made. In this case the difference in the shape of the potential distribution curves may be due soleiy to the influence of the geometry and dimensions of the hull. In the general case the characteristics of the shape and dimensions of a ship's hull may be represented by the shape of the lines of the hull in frame section, the perimeter of the underwater surface of this section and, finally, the principal dimensions of the hull which may in general be characterized by the displacement D. As a first approximation the unknown coefficient K may be represented in the form of a function dependent on the distance from the anode (protector) to the point of observation r and the dimensions of the underwater part of the hull which are expressed by the displacement, i.e. $K = K(r,D)$. To determine the numerical values of these coefficients we measured the potential distribution on ships of various dimensions for an anode with a shield measuring 1500 x 1500 mm mounted in the region of the bilge strake amidships. When the anodes are mounted at the extremities of the hull the value of the potential, other conditions being equal, is 20-30% higher than when the anode is mounted amidships, as was shown by the results of measurements. The measurements of potential were made with reference to silver chloride reference electrodes which were arranged along the line of the hull in the frame section passing through the centre of the anode. At the same time the values of the unknown coefficients were determined as the ratio of the measured shift of potential at a fixed distance from the anode to the results of calculation using formula (1) with h = 0.3 m. As might be expected (Figs. 2,3) the degree of

divergence between the calculated and measured results is significantly influenced by the distance from the anode to the point of observation: near the anode the difference is small, whilst the divergence increases roughly linearly as the distance from the anode increases. The extent of this divergence at a fixed distance from the anode depends on the dimensions of the vessel. Thus, at a distance of 15 m from the anode the calculated potential for a vessel of 16,000 tons displacement differs from the measured potential by a factor of approximately 1.7, whilst for a vessel of 3000 tons displacement the difference exceeds x 3, and for a vessel of 600 tons it is almost x 10.

In view of the linear nature of the dependence of the coefficient K(r,D) on the distance from the point of observation outside the shield it may be represented in the form

$$K(r,D) = 1 + K(D)r,$$

where the quantity K(D) depends solely on the displacement of the ship and is determined by the data shown in Fig. 4. From these data it follows that the dependence of the coefficient K(D) is most marked in the case of vessels with a displacement up to 5000 tons, and less pronounced in the case of larger vessels.

Thus, using the found coefficients and formula (1) we get the following dependence for calculating the distribution of potential over a painted underwater surface of a hull for an anode with an insulation shield:

$$\Delta\varphi(r) = IF_1 [1 + K(D)r],$$

where $F = \frac{\rho_p \gamma}{2\pi} \int_0^\infty \frac{p^{l-02, l_s p}}{\rho_p \gamma p + 1} J_o(pr)dp$; r is the distance from the centre of the anode to the point of observation along the line of the hull; l_s is the length of the side of a square shield (or the diameter of a circular shield); and I is the anode current. The numerical values of the function F_1, calculated on an electronic computer for the most characteristic values of the parameters it contains, are shown in Fig. 5. Similarly, starting with formula (2)

we obtain the calculated dependence of the potential distribution for single protectors and small protector groups:

$$\Delta\varphi(r)\Big|_{r > \frac{l_{rp}}{2}} = IF_2[1 + K(D)r],$$

where $F_2 = \frac{1}{2\pi\gamma r}\left\{1 - \frac{\pi r}{2\gamma\rho_p}\left[E_0\left(\frac{r}{\rho_p\gamma}\right) - N_0\left(\frac{r}{\rho_p\gamma}\right)\right]\right\}$,

r is the distance from the centre of the protector (protector group) to the point of observation along the line of the hull; l_{rp} is the length of the protector (protector group); and I is the current efficiency of the protector (protector group). In the choice of calculated values of ρ_p we can use the dependence of this resistance on the length of service of the ship after the latest painting of the underwater surface, this dependence being obtained by measurements made on vessels painted with ethynol*, the commonest method in the shipbuilding industry[6]. The magnitude of the current efficiency of protectors and protector groups is calculated by the formulas given in[7].

CONCLUSIONS

1. The potential distribution on the underwater surface of ships' hulls in electrochemical protection from sea-water corrosion can be calculated by using formulas for the distribution of the potential of a point source of current situated above or on a linearly polarized plane.

2. Empirical coefficients are introduced to refine the calculated dependences of potential distribution for the main types of electrochemical protection taking account of the lines and dimensions of the hull and the state of the paintwork of the underwater surface.

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*a divinyl acetylene paint - Translator.

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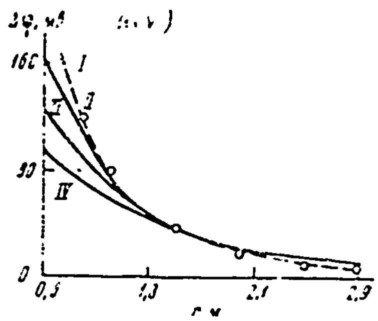

Fig. 1. Comparison of results of calculation of potential distribution for a point source above a linearly polarized plane and results of measurements of potential for an anode with a square shield measuring 1.5 x 1.5 m with a current of 5 A, b = 0.3 $\Omega \cdot m^2$, γ = 2.5 $\Omega \cdot$ m. Distance of source from plane h (metres): I - 0.3; II - 0.5; III - 0.75; IV - 1.0.

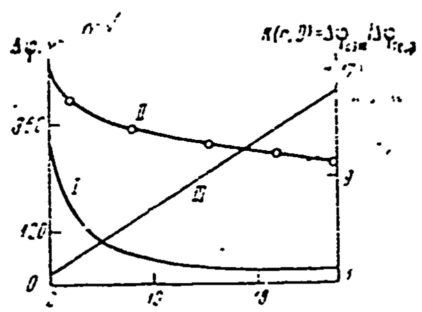

Fig. 2. Results of calculation when h = 0.3 (I) and measurements of potential distribution (II) for a vessel of 600 tons displacement with anode current of 10 A, ρ_p = 51 $\Omega \cdot m^2$, γ = 2.5 1/$\Omega \cdot$ m and values of the coefficient K(r,D) - (III).

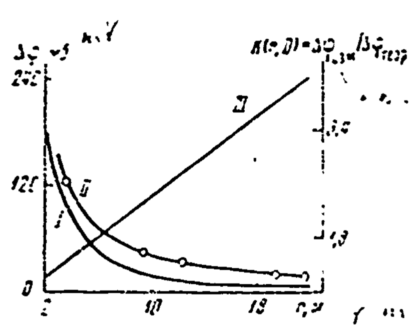

Fig. 3. Results of calculation when h = 0.3 (I) and measurements of potential distribution (II) for a vessel of 3000 tons displacement with current 10 A, ρ_p = 4.1 $\Omega \cdot m^2$, γ = 2.5 1/$\Omega \cdot$ m and values of the coefficient K(r,D) (III).

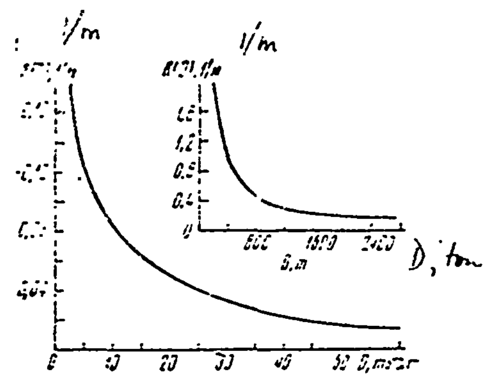

Fig. 4. Dependence of coefficient K(D) on displacement.

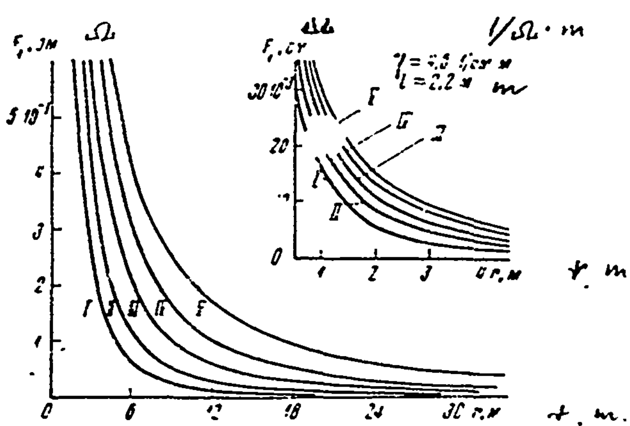

Fig. 5. Values of function F_1 for the calculation of potential distribution for an anode with an insulation shield with values of $\rho_p (\Omega \cdot m^2)$ - I - 0.5; II - 1; III - 2; IV - 4; V - 10.